RuleML Representation and Simulation of Fuzzy Cognitive Maps

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Abstract. Fuzzy Cognitive Map (FCM) technique is a combination of Fuzzy Logic and Artificial Neural Networks that is extensively used by experts and scientists of a diversity of disciplines, for strategic planning, decision making and predictions. A standardized representation of FCMs accompanied by a system that would assist decision makers to simulate their own developed Fuzzy Cognitive Maps would be highly appreciated by them, and would help the dissemination of FCMs. In this paper, a) a RuleML representation of FCM is proposed and b) a system is designed and implemented in Prolog programming language to assist experts to simulate their own FCMs. This system returns results in valid RuleML syntax, making them readily available to other cooperative systems. The representation capabilities and the design choices of the implemented system are discussed and a variety of examples are given to demonstrate the use of the system.

Keywords: Fuzzy Cognitive Maps; RuleML; Simulation; Decision Making; Predictions; Prolog

1 Introduction

Fuzzy Cognitive Map (FCM) is a formal method for making predictions and taking decisions, that is used by scientists from various disciplines. The success of the construction of an FCM is heavily depended on the degree of expertise of the domain experts involved in the FCM construction. Making decisions through FCM, requires the simulation of the FCM model, which is a hard task especially from those scientists that do not possess the necessary computer skills.

Some of the major problems that concern nowadays FCMs are the following:

a) Although many scientists create their own FCMs there is no solid and standard representation of them that would make them easily reusable and transportable.

b) There is not any standard software that would simulate these FCMs, so every scientist has to create his own software system.

c) No repository of FCMs exists to assist their dissemination.

In this paper these problems are handled by developing an XML representation of FCMs, which is based on a popular rule interchange format for the web, namely RuleML (Boley, 2006), accompanied by a Prolog-based simulation system that can assist FCM authors to both create syntactically correct FCMs and simulate their scenarios in FCMs. The basic assumption that we make in this paper is that FCMs closely resemble rules, since they represent causality relations between concepts, something that matches with the logical implication semantics of rules.

This study can provide additional dissemination of the use of FCMs because

a) FCMs authors will have a tool to create and simulate FCM,

b) a RuleML repository of FCMs can be created that will help the concentration and distribution of FCMs and

c) FCMs represented in RuleML will be able to be used in RuleML projects. Additionally, the results of the FCM simulation are stored in RuleML format, making easy their use by other systems.

In this paper, a short introduction to FCMs and related literature is given in section 2. The representation capabilities of RuleML are presented and discussed in section 3. In section 4, the proposed extensions to RuleML in order to be able to represent FCMs are presented. The design of the Prolog-based simulation system that simulates FCMs represented in RuleML is discussed in section 5, followed by a section concerning the implementation and demonstration of the system's capabilities. Finally, in section 7, a summary is presented, accompanied by a number of conclusions and recommendations for further research.

2 Fuzzy Cognitive Maps and Related Literature

Based on Axelord's work on Cognitive Maps (Axelrod, 1976), Kosko introduced in 1986, Fuzzy Cognitive Maps (FCMs) (Kosko, 1986, Kosko, 1992). FCMs are considered a combination of fuzzy logic and artificial neural networks and many researchers have made extensive studies on their capabilities (see for example (Khan et al., 2000, Khan & Quaddus, 2004, Stach et al., 2005, Taber et al., 2006, Tsadiras & Margaritis, 1997). An example of an FCM, concerning a car industry (Eberhart & Dobbins, 1990), is given in Figure 1.

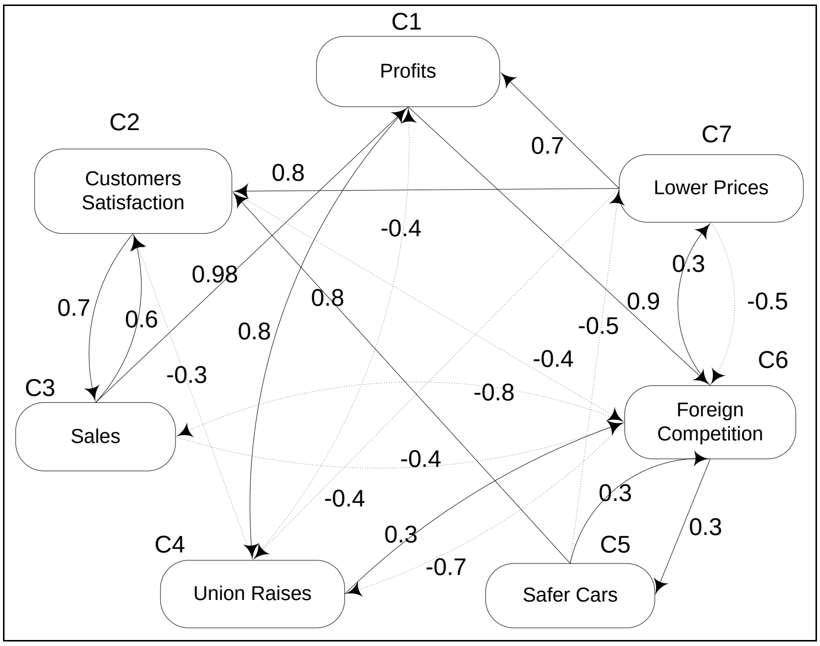


Figure 1: An FCM concerning a car industry (modified version of original taken from Eberhart & Dobbins, (1990)

FCMs create models as collections of concepts and the various causal relations that exist between these concepts. So in figure 1, the nodes represent the concepts that are involved in the model and the directed arcs between the nodes represent causal relationships between the corresponding concepts. The type of the causal relation between the two nodes is determined by the weight that each arc is accompanied. A positive (negative) causal relation between two concepts $\mathrm{C_i}$ and $\mathrm{C_j}$ means that an increase of the activation level of concept $\mathrm{C_i}$ will increase (decrease) $\mathrm{C_j}$ and also a decrease of concept $\mathrm{C_i}$ will decrease (increase) $\mathrm{C_j}$.

The level of activation of each concept $\mathrm{C_i}$ at time step *t* is determined by number $\mathrm{A_i^t}$, i=1,...,n with n to be the number of concepts of the FCM. We define $\mathrm{w_{ij}}$ as the weight of the arc that connects $\mathrm{C_i}$ and $\mathrm{C_j}$. There is synchronous updating to the FCM system which means that $\mathrm{A_i^{t+1}}$, i=1,...,n is calculated by one of the following formulas:

i) $A_i^{t+1} = f_M\,(A_i^t, S_i^t) - d\ A_i^t$ using Certainty Neurons (Tsadiras & Margaritis, 1997a) or (1)

ii) $A_i^{t+1} = f_M(w_{1i}A_1^t, f_M(w_{2i}A_2^t, f_M(..., f_M(w_{n-1,i}A_{n-1}^t, w_{n,i}A_n^t)))) - dA_i^t$ (2)

using Recursive Certainty Neurons (Tsadiras & Margaritis, 1997b)

where,

- $S_i^t = \sum_j w_{ji}A_j^t$ is the sum of the weight influences that concept $\mathrm{C_i}$ receives at time step *t* from all other concepts,
- *d* is a decay factor and
- $$\mathrm{f_M(A_i^t, S_i^t)} = \begin{cases} \mathrm{A_i^t + S_i^t(1 - A_i^t) = A_i^t + S_i^t - S_i^t A_i^t} & \text{if } \mathrm{A_i^t \geq 0, S_i^t \geq 0} \\ \mathrm{A_i^t + S_i^t(1 + A_i^t) = A_i^t + S_i^t + S_i^t A_i^t} & \text{if } \mathrm{A_i^t < 0, S_i^t < 0} \quad \mathrm{|A_i^t|, |S_i^t| \leq 1} \\ \mathrm{(A_i^t + S_i^t) \big/ \left(1 - \min(|A_i^t|, |S_i^t|)\right)} & \text{if } \mathrm{A_i^t S_i^t < 0} \end{cases} \qquad (3)$$

is the function that was used for the aggregation of certainty factors at the MYCIN expert system (Buchanan & Shortliffe, 1984).

Many years have passed since the pioneering work of Taber (1991) on FCM and this technique is still an active research field (Glykas, 2010). The applications of FCMs are numerous and scientists from a wide diversity of disciplines are studying and using them. For example FCMs were developed for analyzing success factors in retail industry (Büyüközkan & Vardaloğlu, 2012) and for the design of controls in business-to-consumer e-commerce systems (Lee & Ahn, 2009). Lee & et al. (2012) used an FCM for personalized pricing of last minute theatre tickets, while Lee & Lee (2011), studied the creation of an Internet-based stock trading system, using an FCM. Kang et al. 2011, created an FCM for the relationship management in airline service. The privatization of a firm was studied by Çoban & Seçme (2005) using an FCM. Trappey et al. (2010), proposed the use of FCMs for RFID reverse logistic management while Kim et al. (2008), used an FCM for forward–backward analysis of RFID-enabled supply chain. FCM models for the analysis in nuclear power reactors have been proposed by Espinosa-Paredes et al. (2009), while Ghaderi et al. (2012) proposed the application of FCMs for studying the electricity markets.

FCMs are also widely used in various areas of medicine. For example, Papageorgiou & Kannappan (2012) have applied FCMs to autism identification, while Giabbanelli et al. (2012) used them for studying the psychosocial determinants of obesity. Lee et al. (2012) used FCMs for the selection of dental implant abutments while Stylios et al. (2008) proposed FCMs for creating medical decision support systems. John & Innocent (2005) used FCMs for modeling uncertainty in clinical diagnosis.

Concerning political science, Andreou et al. (2003) and Tsadiras et al. (2003), proposed FCMs as a Decision Support System for political Decisions.

FCMs are also used in topics concerning ecology (Ramsey and Veltman, 2005, Hobbs et al., 2002) while their forecasting and decision making capabilities are presented in a number of studies e.g. the forecasting of artificial emotions (Salmeron, 2012), the prediction of chaotic time series (Song et al., 2010), multicriteria analysis (Salmeron et al. 2012).

FCMs has also been used for web-mining inference (Lee et al., 2002) and for the navigation of mobile robots (Motlagh et al., 2012).

Although there are many recent attempts toward training and learning of FCMs (Papageorgiou 2012, Papakostas et al. 2012, Stach et al. 2012), the application of FCM technique to a wide variety of scientific areas makes crucial the development of a commonly used tool that can assist the creation and simulation of FCMs. Various attempts have been done towards the creation of such a tool. For example:

- FCM Constructor is a knowledge acquisition system that builds an FCM by direct knowledge acquisition (Cheah et al., 2011).
- FCMapper is an FCM analysis and visualization tool based on MS Excel (http://www.fcmappers.net/).
- The FCM Designer Tool is a tool in Spanish which allows the design of the structure of the FCMs (Jose & Contreras, 2010). The tool handles casual relationships as rules.
- The Fuzzy Cognitive Map applet is an on line calculator and downloadable Java application for FCM computations (http://www.ochoadeaspuru.com/fuzcogmap/index).
- A Java standalone library for FCM computations exists in http://jfcm.megadix.it/.
- FCModeler tool is a Java interface that reads and displays data from an Excel spreadsheet of links and nodes (Dickerson et al., 2001).
- A Java software design for a fuzzy cognitive map modeling tool exists in (Mohr, 1997).

An FCM tool should not only assist the creation and simulation of FCMs but it should also facilitate knowledge sharing and reuse of this knowledge in order to deal with semantic interoperability between different systems. Jung (2012) proposed ontological Cognitive Maps (ontoCM) as an extension to Cognitive Maps that additionally provides semantic information by ontology that is organized on a tree-like hierarchical structure. The semantics of FCMs for the modeling and simulation of complex social, economic and political systems are studied by Carvalho (2012). In our study, we propose the use of RuleML for the representation of FCM that promotes interoperability between different systems and reuse of knowledge.

3 Representation Capabilities of Rules and RuleML

Rule-based systems have been extensively used in several applications and domains, both in academia and industry, such as e-commerce, personalization, games, medicine, etc. They offer a simplistic model for knowledge representation for both domain experts and programmers; experts usually find it easier to express knowledge in a rule-like format and programmers usually find rule-based programming easier to understand and manipulate, decoupling computation from control. The first is performed by the rules whereas the latter is determined by the rule engine itself, that is when and how to apply the rules. In that way, it is more easily to add new rules or data, especially in continuously changing environments.

Nowadays, the Web has evolved in a large repository of information and has become a useful means of communication and knowledge sharing. Rules on the Web come in various formats and with diverse packaging (Boley, 2007). Often, however, the semantics of Web-distributed rule content are compatible. In such cases, rulebases can be reused with an interchange technology consisting of a family of canonical rule languages and bi-directional translators between canonical languages and the languages to be interchanged. The need for Web rule interchange has been increasing with the amount of business rules (incl. policies, regulations, laws), in many domains (e.g. finance, engineering, and healthcare) on the Web (Ross, 2009).

The Rule Markup Language (RuleML) is a markup language designed for the interchange of the major kinds of Web rules in an XML format that is uniform across various rule languages and platforms (Boley, 2006). RuleML was developed to express both forward (bottom-up) and backward (top-down) rules in XML for deduction, rewriting, and further inferential-transformational tasks. The specification of RuleML constitutes a modular hierarchical family of Web sublanguages, whose root accesses the language as a whole and whose members identify customized, combinable subsets of the language. Each of the family's sublanguages has an XML Schema definition, addressed by a URI, which permits inheritance between sublanguage schemas and precise reference to the required expressiveness. The RuleML family's top-level distinctions are derivation rules, queries, and integrity constraints as well as production and reaction rules.

Logic rules are in the form $A \rightarrow B$, whereas A is called antecedent or condition of the rule, while B is the consequent or the conclusion of the rule. The usual semantics of a rule is that whenever the condition is true, then the conclusion is also true. In other words, the existence of the antecedent causes the existence of the consequent (assuming that existence of something in an e.g. database is equivalent to being true).

Fuzzy cognitive mapping (Kosko, 1986) is an extension of cognitive mapping (Axelrod, 1976), which is based on graph theory. An FCM consists of factors (concepts / nodes) which represent the important elements of the mapped system. The directed weighted arcs show the strength of the causal relationships between the factors. Therefore, it is natural to think of rules as a way to represent these causal relationships between concepts. Other scientists also followed this idea, e.g. the FCM system of Jose & Contreras, (2010) handles casual relationships as rules.The concept nodes are equivalent to things being true, whereas the directed arc is equivalent to the implication operation of a rule between the concepts.

For this reason, we have chosen a rule-based representation of FCMs as a basis for a standard representation language. Furthermore, we have chosen RuleML, a de-facto web rule standard, as a candidate language for representing and exchanging FCMs on the Web. To this end, we have slightly modified the RuleML standard, in order to cover all the representational requirements of FCMs. This is detailed in the next section.

4 RuleML representation of FCMs

As it is discussed in section 2, an FCM contains a number of arcs that represent causal relationships between the concepts of the FCM. All these relationships are of the following form:

Concept1 "**influences**" *Concept2* "**with weight**" *W*.

Having justified the isomorphism between causal relationships and rules in the previous section, in this section we detail how FCM causal relationships are being represented in RuleML as rules. The above abstract relationship is represented as follows (in RuleML 1.0[1]), using our mapping scheme:

```
<Implies>
    <if>
          <Atom>
                <op>
                      <Rel>Concept1</Rel>
                </op>
          </Atom>
    </if>
    <then>
          <Atom>
                <degree>
                      <Data>W</Data>
```

[1] http://ruleml.org/1.0/

```
                  </degree>
                  <op>
                        <Rel>Concept2</Rel>
                  </op>
            </Atom>
      </then>
</Implies>
```

Notice that since concepts in FCM are atomic with no parameters, the equivalent atoms in RuleML need not have arguments, so rules are in propositional logic. As an example, the arc between concepts C_2:"*Customers Satisfaction*" and C_3:"*High Sales*" with weight *0.7* in figure 1, which is presented by the following causal relationship:

Customers Satisfaction ***influences*** *Sales* ***with weight*** *0.7,*

is represented by the following RuleML rule:

```
<Implies>
    <if>
          <Atom>
                <op>
                      <Rel>customers satisfaction</Rel>
                </op>
          </Atom>
    </if>
    <then>
          <Atom>
                <degree>
                      <Data>0.7</Data>
                </degree>
                <op>
                      <Rel>sales</Rel>
                </op>
          </Atom>
    </then>
</Implies>
```

Of course, in order to represent a complete FCM with N arcs/causal relationships, we need a RuleML rulebase with N rules as the above. Furthermore, the representation of an FCM also requires statements like the following:

*Concept "**is set to**" Value.*

Statements like the above mean that the activation level of the specific concept should be kept steady to that certain value through the whole simulation process. In RuleML these statements can be represented as facts about concepts referred to by rules, in the following manner:

```
<Atom dynamic="false">
    <degree>
          <Data>Value</Data>
    </degree>
    <op>
          <Rel>Concept</Rel>
    </op>
</Atom>
```

Notice that the **dynamic** attribute is introduced in this paper to the RuleML schema in order to capture the dynamic/static nature of concepts/facts during the simulation process of FCMs. So, for example, to represent in RuleML that *“foreign competition is set to 0.8”* or *“foreign competition is set to high”*, the following RuleML code is needed.

```
<Atom dynamic="false">               <Atom dynamic="false">
  <degree>                             <degree>
    <Data>0.8</Data>                     <Data>high</Data>
  </degree>                            </degree>
  <op>                                 <op>
    <Rel>foreign competition</Rel>       <Rel>foreign competition</Rel>
  </op>                                </op>
</Atom>                              </Atom>
```

A similar representation is required in FCM, for statements like the following:

*Concept “**is initially set to**” Value.*

Statements like the above mean that the activation level of the specific concept initially (at time step 0) is set to the specific value and afterwards, the concept is free to interact with other concepts and to change this value accordingly. In RuleML such statements are presented by facts, setting the **dynamic** attribute to **true**:

```
  <Atom dynamic="true">
    <degree>
      <Data>Value</Data>
    </degree>
    <op>
      <Rel>Concept</Rel>
    </op>
  </Atom>
```

So for example, to represent in RuleML that *“satisfaction is initially set to 0.3”* or *“satisfaction is initially set to low”*, the following RuleML code is needed.

```
<Atom dynamic="true">           <Atom dynamic="true">
  <degree>                        <degree>
    <Data>0.3</Data>                <Data> low </Data>
  </degree>                       </degree>
  <op>                            <op>
    <Rel>satisfaction</Rel>         <Rel>satisfaction</Rel>
  </op>                           </op>
</Atom>                         </Atom>
```

Other parameters, described in section 2, that must be specified are:

a) the type of transfer function that should be used through the simulation (either the *mycin* function for equation 1 or the *recursive* function for equation 2),

b) the value of the decay factor *d*,

In order to represent this global simulation parameter in RuleML, we extended the RuleML schema so that they can be declared in the header of the RuleML document:

<Assert trans-fun="TRANS_FUN" trans-fun-param="decay VALUE">

where **TRANS_FUN** is either *mycin* or *recursive* and **VALUE** is a decimal between 0 and 0.5. For example:

<Assert trans-fun="mycin" trans-fun-param="decay 0.1">

Having defined the above representation of FCM in RuleML, the FCM of Figure 1 can be presented as follows:

```
<?xml version="1.0" encoding="UTF-8"?>
<RuleML xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
                         xsi:schemaLocation="http://www.ruleml.org/1.0/xsd
                         http://dl.dropbox.com/u/3157468/fcm.xsd"
                        xmlns="http://www.ruleml.org/1.0/xsd">
        <Assert trans-fun="mycin" trans-fun-param="decay 0.1">
                <!--  Rules of an FCM concerning a car industry. -->
                <!--  Rule 1 profits influences strikes with weight 0.8. -->
                <Implies>
                        <if>
                                <Atom>
                                        <op>
                                                <Rel>profits</Rel>
                                        </op>
                                </Atom>
                        </if>
                        <then>
                                <Atom>
                                        <degree>
                                                <Data>0.8</Data>
                                        </degree>
                                        <op>
                                                <Rel>strikes</Rel>
                                        </op>
                                </Atom>
                        </then>
                </Implies>
<!--  Rule 2 profits influences foreign competition with weight 0.9.. -->
                <Implies>
                        <if>
                                <Atom>
                                        <op>
                                                <Rel>profits</Rel>
                                        </op>
                                </Atom>
                        </if>
                        <then>
                                <Atom>
                                        <degree>
                                                <Data>0.9</Data>
                                        </degree>
                                        <op>
                                                <Rel>foreign competition</Rel>
                                        </op>
                                </Atom>
                        </then>
                </Implies>
<!--  Rule 3 customers satisfaction influences sales with weight 0.7.. -->
                <Implies>
….
…
…
                </Implies>
<!-- Rule 21 low prices influence foreign competition with weight -0.5.-->
```

```
                <Implies>
                        <if>
                                <Atom>
                                        <op>
                                                <Rel>low prices</Rel>
                                        </op>
                                </Atom>
                        </if>
                        <then>
                                <Atom>
                                        <degree>
                                                <Data>-0.5</Data>
                                        </degree>
                                        <op>
                                                <Rel>foreign competition </Rel>
                                        </op>
                                </Atom>
                        </then>
                </Implies>
                <!--  fact 1. foreign competition is set stable to 0.5. -->
                <Atom dynamic="false">
                        <degree>
                                <Data>0.5</Data>
                        </degree>
                        <op>
                                <Rel>foreign competition</Rel>
                        </op>
                </Atom>
                <!--  fact 2.profits are set initially to 0.3. -->
                <Atom dynamic="true">
                        <degree>
                                <Data>0.3</Data>
                        </degree>
                        <op>
                                <Rel>Profits</Rel>
                        </op>
                </Atom>
        </Assert>
</RuleML>
```

Figure 2: RuleML representation of FCM shown in figure 1.

Finally, in figure 3, we present the schema file for the RuleML-FCM representation, which is actually a minimal reconfiguration of the RuleML 1.0 schema.

```
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
       xmlns:ruleml="http://ruleml.org/spec"
       targetNamespace="http://ruleml.org/spec">
  <xs:redefine schemaLocation="http://www.ruleml.org/1.0/xsd/datalog.xsd">
    <xs:attributeGroup name="Atom.attlist">
      <xs:attributeGroup ref="ruleml:Atom.attlist"/>
      <xs:attribute name="dynamic" type="xs:boolean" use="optional" default="true"/>
    </xs:attributeGroup>
    <xs:attributeGroup name="Assert.attlist">
      <xs:attributeGroup ref="ruleml:Assert.attlist"/>
      <xs:attribute name="trans-fun" type="xs:string" use="optional"/>
      <xs:attribute name="trans-fun-param" type="xs:NMTOKENS" use="optional"/>
    </xs:attributeGroup>
  </xs:redefine>
</xs:schema>
```

Figure 3: RuleML-FCM schema.

5. Design of the RuleML-FCM simulation system

Having represented the FCM in RuleML, the next step is that of simulating the represented FCM. The stages for the simulation of scenarios imposed to FCMs, are shown in figure 4.

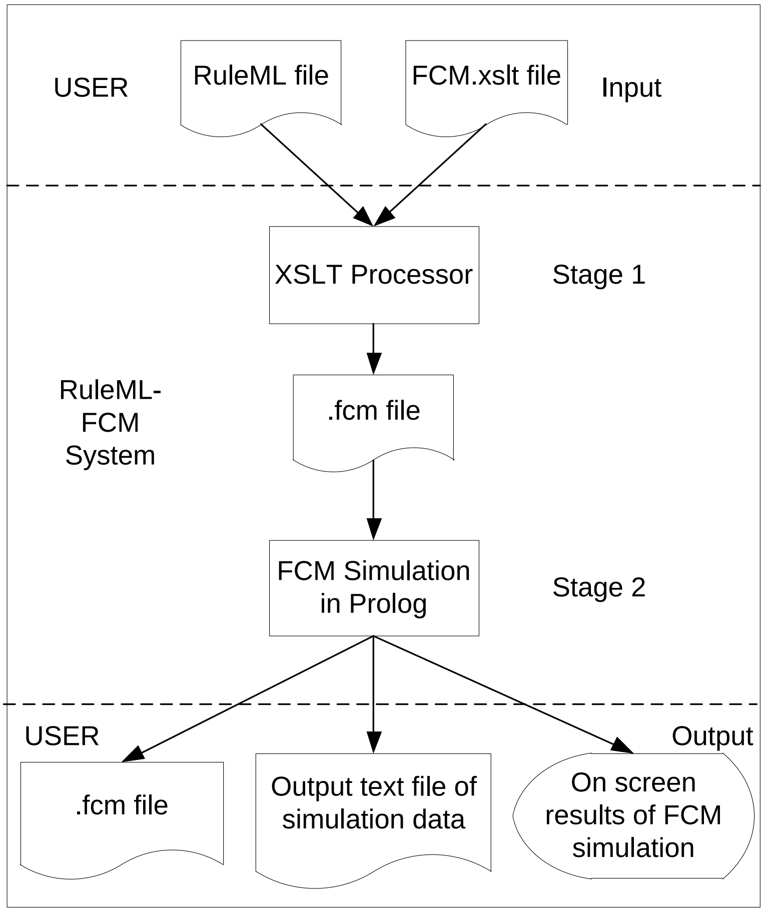


Figure 4. Stages for the simulation of FCM represented in RuleML

In stage 1 of the simulation system a) the RuleML file that represents the FCM and b) the XSLT file of Figure 5, are inputted to an XSLT processor which performs an XSL transformation and produces at the output an FCM text file having statements of the forms shown in figure 6.

```
<?xml version="1.0" encoding="UTF-8"?>
<xsl:stylesheet version="1.0" xmlns:xsl="http://www.w3.org/1999/XSL/Transform"
xmlns:n="http://www.ruleml.org/1.0/xsd">
        <xsl:output method="text" version="1.0" encoding="UTF-8" indent="yes"/>
        <xsl:template match="/">
                <xsl:apply-templates select=".//n:Assert"/>
        </xsl:template>
        <xsl:template match="n:Assert">
        use <xsl:value-of select="@trans-fun"/> with <xsl:value-of select="@trans-fun-
param"/> .
        <xsl:apply-templates select="n:Implies"/>
                <xsl:apply-templates select="n:Atom"/>
        </xsl:template>
        <xsl:template match="n:Implies">
                <xsl:value-of select="n:if//n:Rel"/> influences <xsl:value-of
select="n:then//n:Rel"/> with weight <xsl:value-of select="n:then//n:degree/n:Data"/>
.
```

```
        </xsl:template>
        <xsl:template match="n:Atom">
                <xsl:value-of select=".//n:Rel"/> is set <xsl:choose><xsl:when
test="@dynamic='true'"> initially to </xsl:when><xsl:otherwise> stable to
</xsl:otherwise></xsl:choose><xsl:value-of select=".//n:degree/n:Data"/> .
        </xsl:template>
</xsl:stylesheet>
```

Figure 5: XSLT file for transforming the RuleML representation to a textual FCM representation.

Concept1 "influences" Concept2 "with weight" W.

Concept "is set to" Value.

Concept "is initially set to" Value.

"use" mycin/recursive " with decay" D .

Figure 6. Generic statements in the textual FCM file.

Using the above transformation in stage 1, the RuleML representation of the FCM of figure 2 will transformed to that shown in figure 7, and it will be saved to an `.fcm` file. It is apparent from figure 7, that the FCM in the .`fcm` file is represented to a format close to natural language, which makes more intuitive the interactions that exists in it.

```
profits influences strikes with weight 0.8.
profits influences foreign competition with weight 0.9.
customers satisfaction influences sales with weight 0.7.
customers satisfaction influences foreign competition with weight -0.4.
sales influences profits with weight 0.98.
sales influences  customers satisfaction with weight 0.6.
sales influences foreign competition with weight -0.4.
strikes influences profits with weight -0.4.
strikes influences  customers satisfaction with weight -0.3.
strikes influences foreign competition with weight 0.7.
safe cars influences customers satisfaction with weight 0.8.
safe cars influences foreign competition with weight 0.3.
safe cars influences low prices with weight -0.5.
foreign competition influences sales with weight -0.8.
foreign competition influences strikes with weight -0.7.
foreign competition influences safe cars with weight 0.3.
foreign competition influences low prices with weight 0.3.
low prices influences customers satisfaction with weight 0.8.
low prices influences profits with weight 0.7.
low prices influences strikes with weight -0.4.
low prices influences foreign competition with weight -0.5.

foreign competition is set to 0.5.
use mycin with decay 0.1.
```

Figure 7. Content of the `.fcm` file containing the transformation of the RuleML representation of the FCM shown in figure 1

5.1 Design of the Prolog subsystem of the RuleML-FCM simulation system

To execute the FCM represented in the form of figure 6, a program written in the Prolog programming language (Bratko, 2000) has been created. The main reasons for choosing Prolog are:

a) Statements of figure 7 resemble logical facts of the Prolog language.

b) Statements of figure 7 suit the declarative nature of Prolog.

c) Prolog has been used successfully in Natural Language Processing (Sharp, 1991).

d) The grammar of the statements in figure 7 can be directly handled by Prolog. This grammar, written in valid Prolog syntax, appears in figure 8.

```
statement-->concept,[influences],concept,[with,weight],value.
statement-->concept,[is,set,to],value.
statement-->concept,[is,initially,set,to],value.

statement-->[use,mycin,with,decay],number05.
statement-->[use,recursive,with,decay],number05.

concept-->[X].
concept-->[X],concept.

value-->[X],{number(X)},{X=<1}, {-1=<X}.
value--> [X], {member(X,[low,average, high])}.
value-->[very,high].
value-->[very,low].

number05--> [X],{number(X)},{X=<0.5}, {0=<X}.
```

Figure 8. Grammar of statements in figure 7

In the above grammar:

a) "*Concept*" is defined as a series of one or more words.

b) "*Value*" is considered either any number in the interval [-1,1], or a linguistic value such as "*very low*", "*low*", "*average*", "*high*" and "*very high*". These linguistic values during execution are translated to the values 0.1, 0.3, 0.5, 0.7, 0.9, respectively.

c) Decay factor is allowed to have a numerical value in the interval [0, 0.5].

The above syntax contains all the necessary facilities for parsing the textual FCM output file created in stage 1 of the system, but also bears certain restrictions in order to prevent the user from representing ambiguities or introducing misunderstandings.

The simulation of the FCM is performed in stage 2 of the system (see figure 2) by the developed Prolog application. A preliminary version of this application was presented in (Tsadiras, 2008). FCM can reach a) an equilibrium point, b) a limit circle periodical behaviour or c) a chaotic behaviour (Tsadiras & Margaritis 1999)]. If an equilibrium point is reached, i) the activation levels of all FCM's concepts at equilibrium are shown on the computer screen, ii) these activation levels are saved to an output file in a RuleML format as a set of facts, to make them available for use by other systems and iii) the activation levels of the concepts of the FCM model through the transition phase towards this equilibrium point are saved in a ".txt" data file for possible further examination. If the FCM reaches a limit circle behaviour or a chaotic behaviour then the system simulates 10000 time steps of interaction and saves the activation levels of the concepts of the FCM model through these 10000 time steps to a “.txt” file for further examination to a graph plotting software tool.

6. Implementation and Demonstration of the RuleML-FCM Simulation System

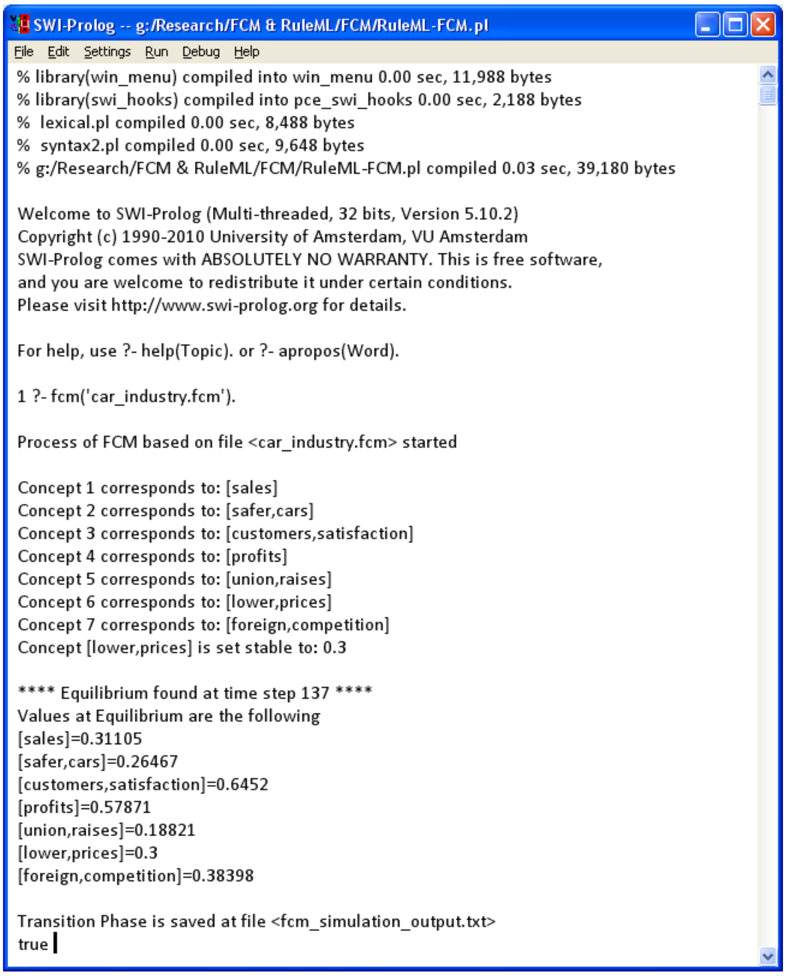
The RuleML-FCM simulation system is implemented in SWI-Prolog (http://www.swi-prolog.org/), following the design described in section 5. To demonstrate its implementation, the FCM of figure 1 will be used, that imposes scenario #1. According to this scenario, “lower price is set to 0.3” so it attempts to predict the consequences of a small decrease at the prices of the cars, by the car industry. To examine this scenario, the RuleML representation of FCM of figure 1(as shown in figure 2) is saved to a file called ‘car_industry.ruleml’ and inserted to the RuleML-FCM system together with the fcm.xslt file of figure 5.

The output of the system is shown in figure 9. Seven (7) different concepts are identified and one of them, concept “*lower prices*”, is set constant to 0.3. After 137 time steps, FCM reaches an equilibrium point to the state that is presented in figure 9.

From that, we can conclude that the small decrease at the prices of the cars (0.3), leads to a significant increase to customers satisfaction (0.6452) and also to profits (0.57871). Sales are increased (0.31105) and the same applies to foreign competition (0.38398). There is a small pressure to create safer cars (0.24467) and a small increase to union claims (0.18821).

The data of the interactions during the 137 time steps are saved to an output text file. This file can be processed by a graph plotting software tool and the transition phase towards equilibrium can be exhibited. This transition phase for the case above is shown in figure 10.

Additionally, a RuleML output file is created, as shown in figure 11, containing the activation levels of all FCM’s concepts at equilibrium point, represented as RuleML facts. This facilitates the use of FCM’s results by other systems, using the common RuleML representation.


SWI-Prolog -- g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl
File Edit Settings Run Debug Help

```
% library(win_menu) compiled into win_menu 0.00 sec, 11,988 bytes
% library(swi_hooks) compiled into pce_swi_hooks 0.00 sec, 2,188 bytes
%  lexical.pl compiled 0.00 sec, 8,488 bytes
%  syntax2.pl compiled 0.00 sec, 9,648 bytes
% g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl compiled 0.03 sec, 39,180 bytes

Welcome to SWI-Prolog (Multi-threaded, 32 bits, Version 5.10.2)
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For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- fcm('car_industry.fcm').

Process of FCM based on file <car_industry.fcm> started

Concept 1 corresponds to: [sales]
Concept 2 corresponds to: [safer,cars]
Concept 3 corresponds to: [customers,satisfaction]
Concept 4 corresponds to: [profits]
Concept 5 corresponds to: [union,raises]
Concept 6 corresponds to: [lower,prices]
Concept 7 corresponds to: [foreign,competition]
Concept [lower,prices] is set stable to: 0.3

**** Equilibrium found at time step 137 ****
Values at Equilibrium are the following
[sales]=0.31105
[safer,cars]=0.26467
[customers,satisfaction]=0.6452
[profits]=0.57871
[union,raises]=0.18821
[lower,prices]=0.3
[foreign,competition]=0.38398

Transition Phase is saved at file <fcm_simulation_output.txt>
true
```

Figure 9: Output of RuleML - FCM simulation system for an FCM concerning a Car Industry. Scenario #1: Lower Prices is set to 0.3. Equilibrium reached after 137 time steps

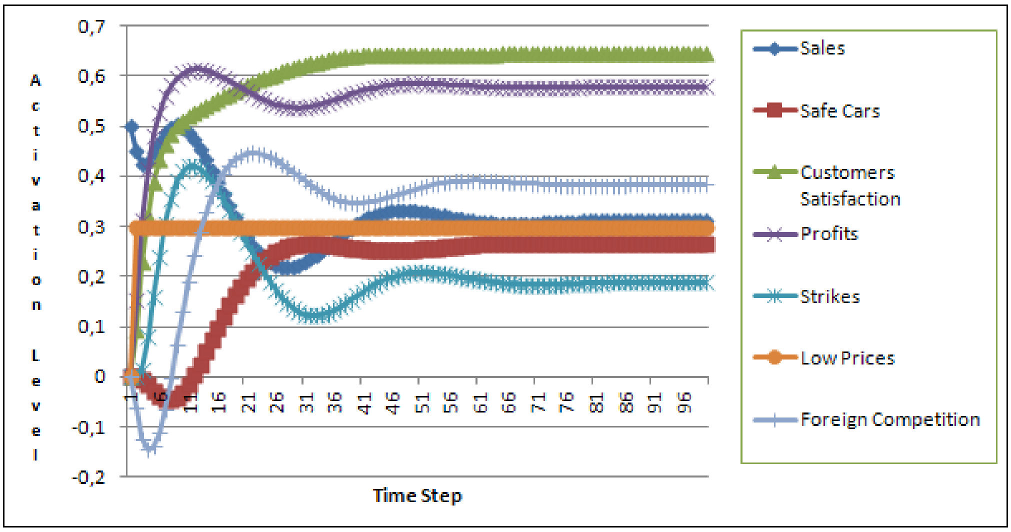


Figure 10. Transition phase towards equilibrium for scenario #1.

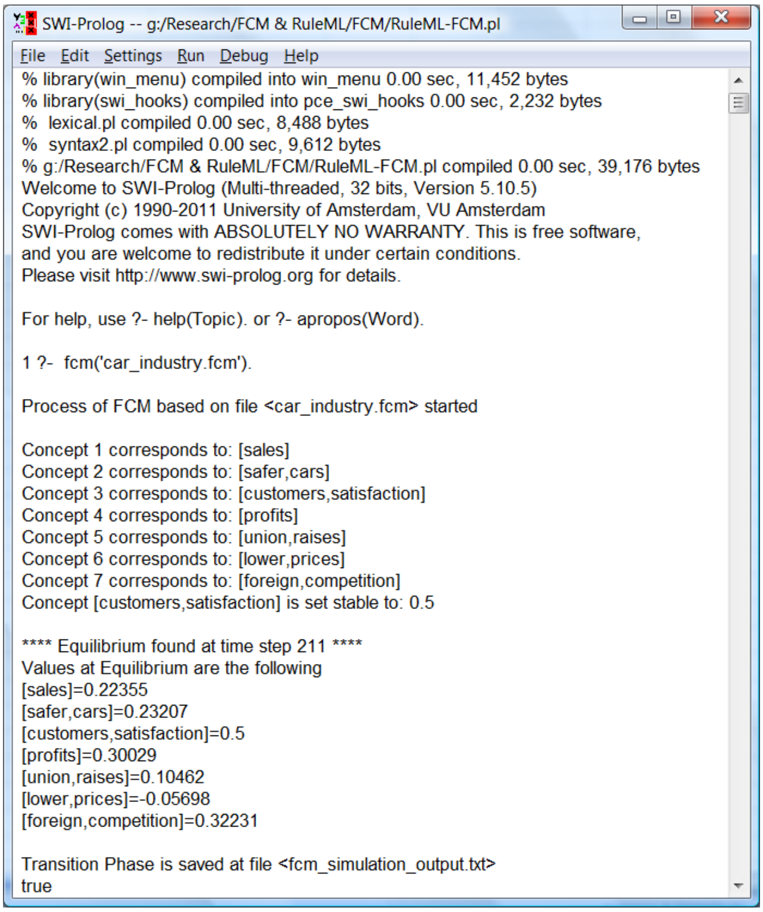
```
<RuleML xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
```

```
       xsi:schemaLocation="http://ruleml.org/spec
                          http://dl.dropbox.com/u/3157468/fcm.xsd"
       xmlns="http://ruleml.org/spec">
  <Assert>
    <Atom>
      <degree><Data>0.38398</Data></degree>
      <op><Rel>foreign competition</Rel></op>
    </Atom>
    <Atom>
      <degree><Data>0.3</Data></degree>
      <op><Rel>lower prices</Rel></op>
    </Atom>
    <Atom>
      <degree><Data>0.18821</Data></degree>
      <op><Rel>union raises</Rel></op>
    </Atom>
    <Atom>
      <degree><Data>0.57871</Data></degree>
      <op><Rel>profits</Rel></op>
    </Atom>
    <Atom>
      <degree><Data>0.6452</Data></degree>
      <op><Rel>customers satisfaction</Rel></op>
    </Atom>
    <Atom>
      <degree><Data>0.26467</Data></degree>
      <op><Rel>safer cars</Rel></op>
    </Atom>
    <Atom>
      <degree><Data>0.31105</Data></degree>
      <op><Rel>sales</Rel></op>
    </Atom>
  </Assert>
</RuleML>
```

Figure 11. RuleML output file representating the activation levels of FCM's Transition phase towards equilibrium for scenario #1.

Other "what-if" scenarios can be checked with the system, in order the decision maker to examine the predicted outcomes according to the FCM. Let's imagine that we would like to predict the consequences of a moderate increase to "*customers satisfaction*". To simulate this scenario, concept "*customers satisfaction*" should be set constant to value "0.5".

Running this new scenario #2, the outcome is that of figure 11. Once again seven (7) different concepts are identified, and one of them, concept "*customers satisfaction*", is set constant to 0.5. After 211 time steps, FCM reached an equilibrium point, with the concepts to be activated to the degree shown in figure 12. It can be concluded that according to the FCM predictions, the moderate increase to customers satisfaction leads to small increase in sales (0.22355) and profits (0.30029). Prices remain almost the same (-0.05698), while there is very small increase to union claims (0.10462). There is small pressure to produce safer cars, and the foreign competition is increased (0.32231). A RuleML output file is created, containing the activation levels of FCM's concepts at equilibrium. Additionally, an output text file is created, containing the data of the interactions during the 211 time steps. Figure 13 exhibits the transition phase towards equilibrium, based on this data.


SWI-Prolog -- g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl
File Edit Settings Run Debug Help

```
% library(win_menu) compiled into win_menu 0.00 sec, 11,452 bytes
% library(swi_hooks) compiled into pce_swi_hooks 0.00 sec, 2,232 bytes
%  lexical.pl compiled 0.00 sec, 8,488 bytes
%  syntax2.pl compiled 0.00 sec, 9,612 bytes
% g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl compiled 0.00 sec, 39,176 bytes
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Please visit http://www.swi-prolog.org for details.

For help, use ?- help(Topic). or ?- apropos(Word).

1 ?-  fcm('car_industry.fcm').

Process of FCM based on file <car_industry.fcm> started

Concept 1 corresponds to: [sales]
Concept 2 corresponds to: [safer,cars]
Concept 3 corresponds to: [customers,satisfaction]
Concept 4 corresponds to: [profits]
Concept 5 corresponds to: [union,raises]
Concept 6 corresponds to: [lower,prices]
Concept 7 corresponds to: [foreign,competition]
Concept [customers,satisfaction] is set stable to: 0.5

**** Equilibrium found at time step 211 ****
Values at Equilibrium are the following
[sales]=0.22355
[safer,cars]=0.23207
[customers,satisfaction]=0.5
[profits]=0.30029
[union,raises]=0.10462
[lower,prices]=-0.05698
[foreign,competition]=0.32231

Transition Phase is saved at file <fcm_simulation_output.txt>
true
```

Figure 12: Output of RuleML - FCM simulation system for an FCM concerning a Car Industry. Scenario #2: Customers satisfaction is set to 0.5. Equilibrium found after 211 time steps.

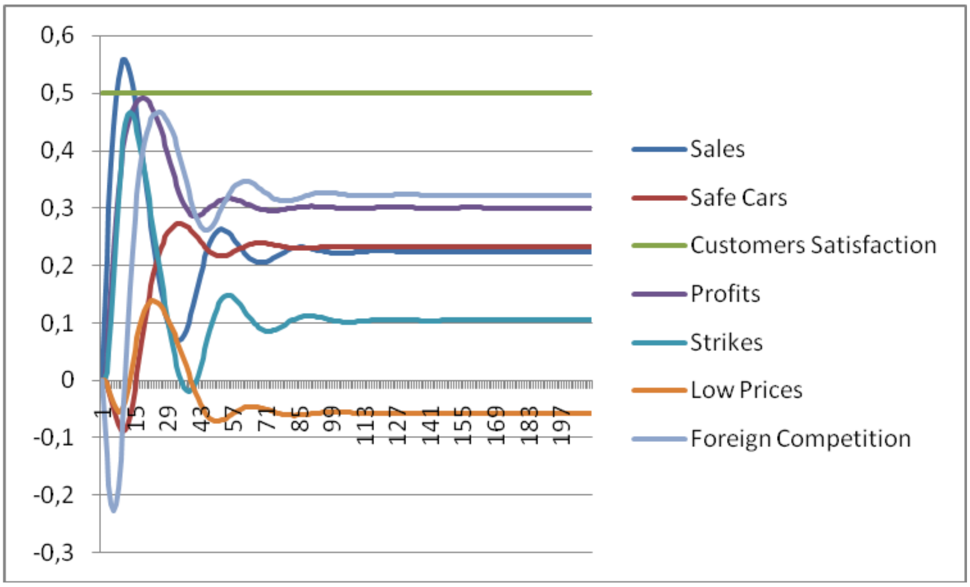
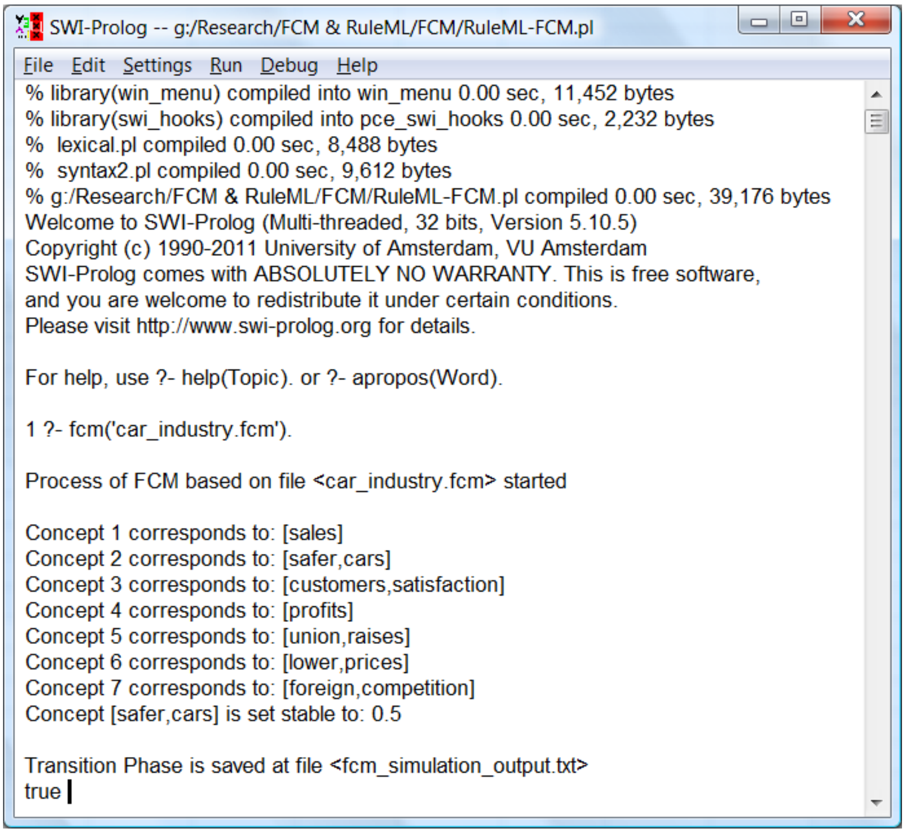


Figure 13. Transition phase towards equilibrium for scenario #2.

Another scenario (scenario #3) is tried with the system, to examine the consequences of a decision to manufacture quite safer cars (“safer cars” is set stable to 0.5). Running this scenario in the system, the outcome is that of figure 14.


SWI-Prolog -- g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl
File Edit Settings Run Debug Help

```
% library(win_menu) compiled into win_menu 0.00 sec, 11,452 bytes
% library(swi_hooks) compiled into pce_swi_hooks 0.00 sec, 2,232 bytes
%  lexical.pl compiled 0.00 sec, 8,488 bytes
%  syntax2.pl compiled 0.00 sec, 9,612 bytes
% g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl compiled 0.00 sec, 39,176 bytes
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For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- fcm('car_industry.fcm').

Process of FCM based on file <car_industry.fcm> started

Concept 1 corresponds to: [sales]
Concept 2 corresponds to: [safer,cars]
Concept 3 corresponds to: [customers,satisfaction]
Concept 4 corresponds to: [profits]
Concept 5 corresponds to: [union,raises]
Concept 6 corresponds to: [lower,prices]
Concept 7 corresponds to: [foreign,competition]
Concept [safer,cars] is set stable to: 0.5

Transition Phase is saved at file <fcm_simulation_output.txt>
true
```

Figure 14: Output of RuleML - FCM simulation system for an FCM concerning a Car Industry. Scenario#3:“Safer cars” is set to 0.5.

No equilibrium point is found even after making 10000 time steps. Conclusions can only be drawn by studying the transition phase, which is saved in the output file. The transition phase according to the data of this output file is shown in figure 15. It is apparent that FCM exhibits damped oscillation behavior. From studying the values that concepts reach after the damped oscillations (shown in Table 1) the various conclusions can be drawn. The construction of safer cars (0.5) leads to an increase in customers satisfaction (0.46296) and also to a small increase in sales (0.28915). On the other hand, there is an increase in prices (low prices=-0.3565) and in foreign competition (0.24235). Profits (0.05112) and union rises (0.04135) remain stable. The fact that this equilibrium point is reached after damped oscillation behavior and after a long transition phase, indicates that there are strong interactions between the concepts of the FCM, before they reach the equilibrium point.

Table 1. Equilibrium point after damped oscillation behavior of scenario #3.

Sales	Safe Cars	Customers Satisfaction	Profits	Union Rises	Low Prices	Foreign Competition
0.28915	0.5	0.46296	0.05112	0.04135	-0.3565	0.24235

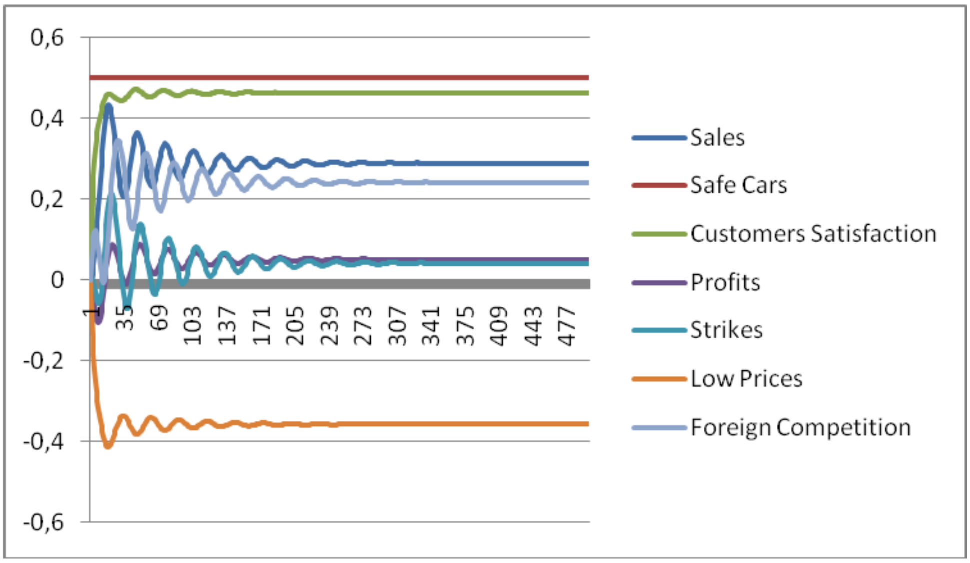
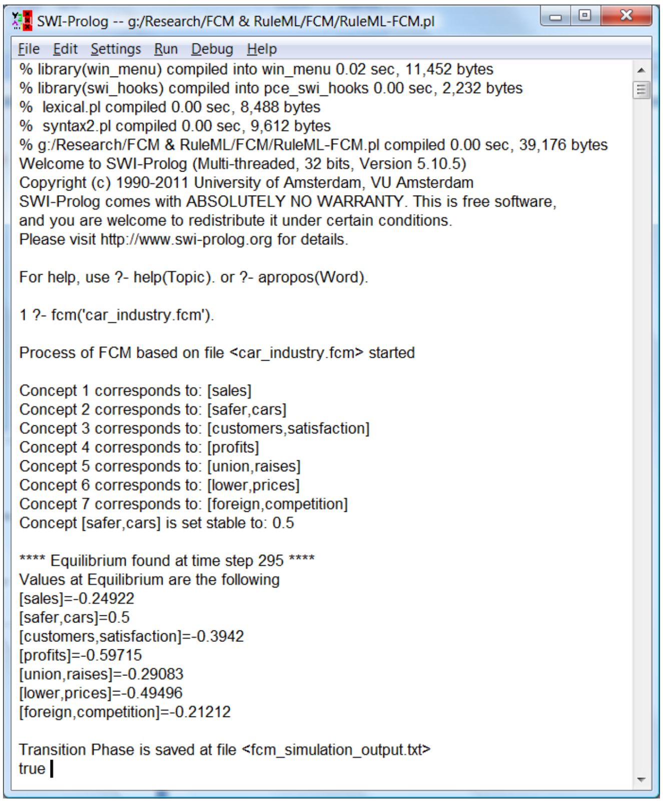


Figure 15. Transition phase of an FCM concerning a car industry for scenario #3. Damped oscillation behaviour is exhibited.

Scenarios can also run in the RuleML-FCM system by changing one or more weights of the connections between FCM's concepts. For example, in scenario #4, is similar to scenario #3 ("*safer cars*" is set stable to 0.5) but in scenario #4 the weight of the influence of "*safer cars*" to "*customer satisfaction*" is 0.5, instead of 0.8 that is in scenario#3. In other words, scenario #4 examines how scenario #3 is affected by a change of the strength that "*safer cars*" influences "*customers satisfaction*". Running this scenario in the system, the outcome is that of figure 16.



```
% library(win_menu) compiled into win_menu 0.02 sec, 11,452 bytes
% library(swi_hooks) compiled into pce_swi_hooks 0.00 sec, 2,232 bytes
%  lexical.pl compiled 0.00 sec, 8,488 bytes
%  syntax2.pl compiled 0.00 sec, 9,612 bytes
% g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl compiled 0.00 sec, 39,176 bytes
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For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- fcm('car_industry.fcm').

Process of FCM based on file <car_industry.fcm> started

Concept 1 corresponds to: [sales]
Concept 2 corresponds to: [safer,cars]
Concept 3 corresponds to: [customers,satisfaction]
Concept 4 corresponds to: [profits]
Concept 5 corresponds to: [union,raises]
Concept 6 corresponds to: [lower,prices]
Concept 7 corresponds to: [foreign,competition]
Concept [safer,cars] is set stable to: 0.5

**** Equilibrium found at time step 295 ****
Values at Equilibrium are the following
[sales]=-0.24922
[safer,cars]=0.5
[customers,satisfaction]=-0.3942
[profits]=-0.59715
[union,raises]=-0.29083
[lower,prices]=-0.49496
[foreign,competition]=-0.21212

Transition Phase is saved at file <fcm_simulation_output.txt>
true |
```

Figure 16: Output of RuleML - FCM simulation system for an FCM concerning a Car Industry. Scenario#4:"Safer cars" is set to 0.5. "safer cars" influences "customer satisfaction" with weight 0.5 (instead of 0.8 that is in scenario#3).

After 295 time steps, FCM reached an equilibrium point, with the concepts to be activated to the degrees shown in figure 15. It can be concluded that according to the FCM predictions, the construction of safer cars (0.5) leads to a clear increase in prices (low prices=-0.49496). This can justify the decrease in sales (-0.24922) and profits (-0.59715). Customers are getting less satisfied (-0.3942), and there is a decrease in both union raises (-0.29083) and foreign competition (-0.21212). The transition phase according to the data of the output file is shown in figure 17, exhibiting similar dynamic behaviour (damped oscillations) with that of scenario #3. A RuleML output file is also created, containing the activation levels of FCM's concepts at equilibrium.

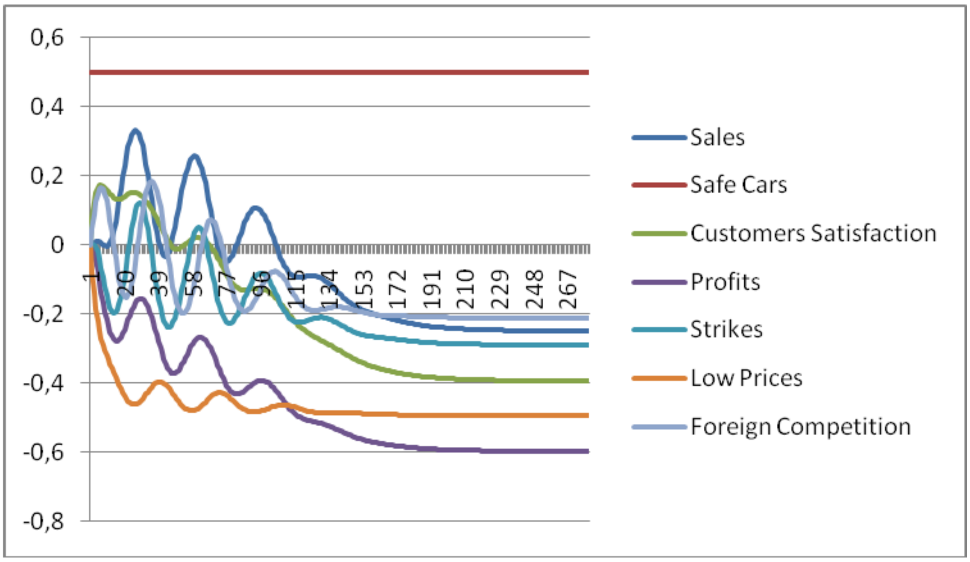


Figure 17. Transition phase of an FCM concerning a car industry for scenario #4. Equilibrium reached after 295 time steps

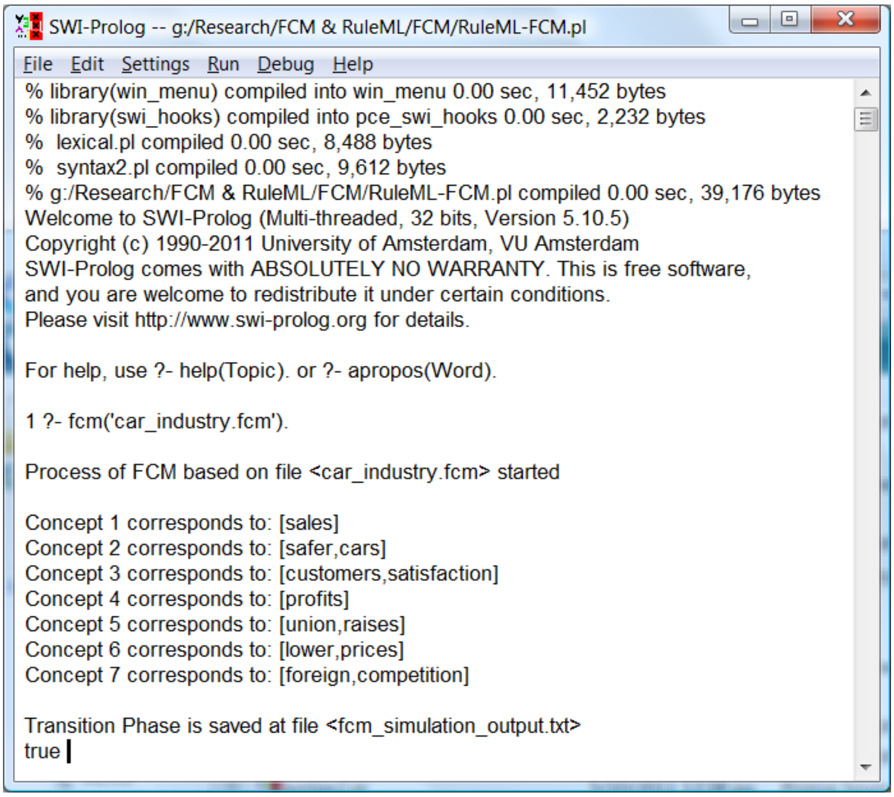
For the car industry, scenario #4 is much worse than scenario #3. It is interesting to notice that the results of the same action (construction of better cars) can lead to completely different outcome, even when a single interaction in FCM is changed (in scenario #4, "*safer cars*" influences "*customer satisfaction*" with weight 0.5, while in scenario #3 the weight of the same influence is 0.8). This indicates that:

a) Experts should be very careful when they create an FCM.

b) Decision makers, by using FCMs, can also be supported in their decisions by examining scenarios that involve the change of the weights between the interactions of the FCM's concepts.

c) Decision makers can also use results of FCM's scenarios, in order to examine what structural changes should strategically be done, in order to reach the desired results.

In the last scenario that is examined in this study (scenario #5), no concept is set to a specific level but all concepts are free to interact with each other. Imposing this scenario, the system returns the results of figure 18. No equilibrium point is reached after 10000 iterations. To examine the dynamical behaviour of this scenario, figure 19 is created based on the data of the output file. It is apparent that the FCM enters a limit cycle behaviour where all concepts are getting high and low periodically. For the car industry, it can be concluded that these concepts will constantly increase and decrease, meaning that there will be strong interactions in the car industry and no equilibrium for this scenario.



```
% library(win_menu) compiled into win_menu 0.00 sec, 11,452 bytes
% library(swi_hooks) compiled into pce_swi_hooks 0.00 sec, 2,232 bytes
%  lexical.pl compiled 0.00 sec, 8,488 bytes
%  syntax2.pl compiled 0.00 sec, 9,612 bytes
% g:/Research/FCM & RuleML/FCM/RuleML-FCM.pl compiled 0.00 sec, 39,176 bytes
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For help, use ?- help(Topic). or ?- apropos(Word).

1 ?- fcm('car_industry.fcm').

Process of FCM based on file <car_industry.fcm> started

Concept 1 corresponds to: [sales]
Concept 2 corresponds to: [safer,cars]
Concept 3 corresponds to: [customers,satisfaction]
Concept 4 corresponds to: [profits]
Concept 5 corresponds to: [union,raises]
Concept 6 corresponds to: [lower,prices]
Concept 7 corresponds to: [foreign,competition]

Transition Phase is saved at file <fcm_simulation_output.txt>
true
```

Figure 18: Output of RuleML - FCM simulation system for an FCM concerning a Car Industry. Scenario#5: All concepts are free to interact.

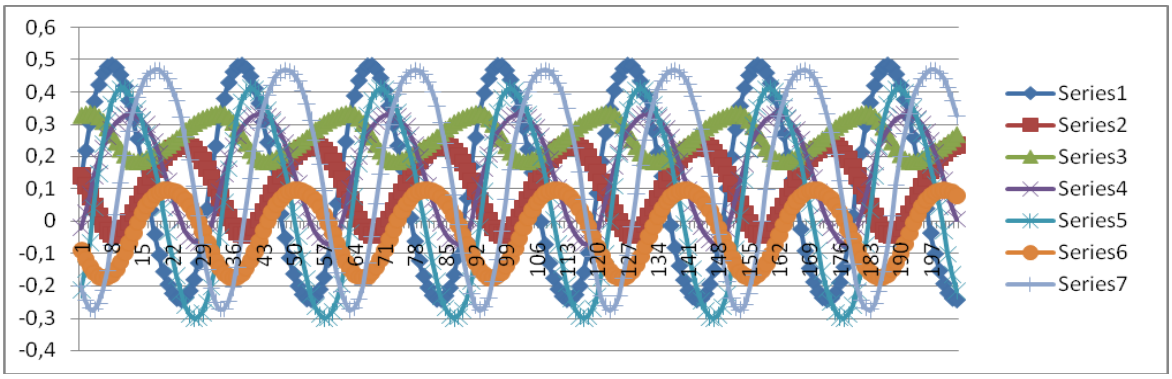

Figure 19. Transition phase of an FCM concerning a car industry for scenario #5. Limit cycle behaviour is reached.

More scenarios can be created and the predicted outcome will be immediately received. This is highly appreciated by decision makers that are willing to examine a number of "what-if" scenarios and check the predicted consequences of these scenarios.

6. Summary – Conclusions

After a short introduction to Fuzzy Cognitive Maps and RuleML, a RuleML representation of FCMs is proposed that make:

a) FCMs easily transferable and reusable.
b) FCMs ready to interact with other systems that interact with RuleML.
c) Easy the creation of a repository of FCMs, that is important for FCM researchers and practitioners.

A system for simulating RuleML representation of FCMs is designed and implemented in order to:

a) Simulate the scenario written in the form of the RuleML representation of FCM.
b) Present the equilibrium point of the imposed scenario (if such a point exists).
c) Produce a RuleML output file that contains the activation levels of FCM's concepts at equilibrium.
d) Produce an output file that contains the data of the transition phase to visualize it, if the user wants to.

The use of the system above is illustrated using a number of examples, to prove its utility for decision makers working with FCMs. The main reasons for that are the facts that:

a) The representation of FCMs in RuleML is simple.
b) No programming skills are required to create and simulate FCMs.
c) A number of different scenarios can be tested easily and quickly, having the decision maker focused on the FCM itself and not to computer technicalities.

In the future we would like to work towards the following improvements to the usability of the system:

- Integrate the various functionalities of the system into a single stand-alone web application that will help disseminate FCM research and development.
- Create a repository of FCMs represented in RuleML in which web users will be able to import and export various FCMs.
- Develop user-friendly editor(s) for building FCMs, such as a natural language interface to feed directly the Prolog simulator (e.g. in ACE (Fuchs et al., 2006)), and/or a graphical/visual RuleML-ware editor, as in (Kontopoulos et al., 2008).
- Make the input and output data of FCM compliant to the linked open data initiative[2] so that at least initial concept activations and concept activations at equilibrium can be interchanged with other systems using RDF triples. Of course, this step also requires the definition of an appropriate ontology, which should be properly linked with other scientific ontologies.

References

Andreou A. S., Mateou, N. H. & Zombanakis, G. A., (2003), The Cyprus Puzzle And The Greek - Turkish Arms Race: Forecasting Developments Using Genetically Evolved Fuzzy Cognitive Maps, Defence and Peace Economics, vol.14, no. 4. p.p 293 – 310.

Axelrod, R., (1976). Structure of Design, Princeton: Princeton University Press.

Boley, H., (2006). The RuleML Family of Web Rule Languages. In: Alferes, J.J., Bailey, J., May, W., Schwertel, U. (eds.) PPSWR 2006. LNCS, vol. 4187, pp. 1–17, Springer.

Boley, H., (2007). Are Your Rules Online? Four Web Rule Essentials, Keynote speech at Int. RuleML Symposium on Rule Interchange and Applications (RuleML-2007), October 25-26, 2007, Orlando, Florida, USA, Springer-Verlag, LNCS 4824, pp. 7–24.

Bratko I. (2000). Prolog–Programming for Artificial Intelligence, Addison Wesley, 3rd edition.

Buchanan, B. G. & Shortliffe E. H., (1984). Rule-Based Expert Systems. The MYCIN Experiments of the Stanford Heuristic Programming Project, Reading, MA: Addison-Wesley.

Büyüközkan G. & Vardaloğlu Z. (2012). Analyzing of CPFR success factors using fuzzy cognitive maps in retail industry, Expert Systems with Applications, vol. 39, no. 12, pp.10438-10455.

Carvalho, J.P., (2012). On the semantics and the use of fuzzy cognitive maps and dynamic cognitive maps in social sciences, Fuzzy Sets and Systems, In Press, Corrected Proof, available online 3 January 2012.

Cheah, W.P., Kim, Y.S., Kim, K.Y & Yang, H.J., (2011). Systematic causal knowledge acquisition using FCM Constructor for product design decision support, Expert Systems with Applications, vol. 38, no. 12, pp. 15316-15331.

Çoban, O. & Seçme, G., (2005). "Prediction of socio-economical consequences of privatization at the firm level with fuzzy cognitive mapping", Information Sciences: an International Journal, vol.169, no.1-2, pp.131-154.

[2] http://linkeddata.org/

Dickerson, J.A., Berleant, D., Cox, Z., Qi, W. & Wurtele, E., (2001). Creating Metabolic Network Models using Text Mining and Expert Knowledge, Atlantic Symposium on Molecular Biology and Genome Information Systems and Technology (CBGIST 2001), Durham, North Carolina.

Eberhart, R.C., Dobbins, R.W., (1990). Neural Network PC Tools, Academic Press.

Espinosa-Paredes, G., Nuñez-Carrera, A., Vazquez-Rodrigue,z A. & Espinosa-Martinez, E.-G. (2009). Modeling of the High Pressure Core Spray Systems with fuzzy cognitive maps for operational transient analysis in nuclear power reactors, Progress in Nuclear Energy, vol. 51, no. 3, pp. 434-442.

Fuchs, N.E. , Kaljurand, K., Schneider, G., (2006). "Attempto Controlled English Meets the Challenges of Knowledge Representation, Reasoning, Interoperability and User Interfaces", FLAIRS Conference 2006, pp. 664-669.

Ghaderi, S.F., Azadeh, A., Nokhandan, P.B. & Fathi, E.,(2012). Behavioral simulation and optimization of generation companies in electricity markets by fuzzy cognitive map, Expert Systems with Applications, vol. 39, no. 5, pp. 4635-4646.

Giabbanelli, P.J., Torsney-Weir, T .& Kumar, V., (2012). Mago A fuzzy cognitive map of the psychosocial determinants of obesity, Applied Soft Computing, In Press, Corrected Proof, available online 28 February 2012.

Glykas, M., (2010). Fuzzy Cognitive Maps: Advances in Theory, Methodologies, Tools and Applications, Studies in Fuzziness and Soft Computing, vol. 247, 2010.

Hobbs B.F., Ludsin S., Knight R.L., Ryan P.A. & Biberhofer J., (2002), Fuzzy Cognitive Mapping as a Tool to Define Management Objectives for Complex Ecosystems, Ecological Applications, vol.12, no. 5, pp.1548-1565.

John, R.I. & Innocent, P.R., (2005). Modeling uncertainty in clinical diagnosis using fuzzy logic, IEEE Transactions on Systems, Man and Cybernetics, vol.35, no.6, pp.1340- 1350.

Jose A. & Contreras J., (2010). The FCM Designer Tool in "Fuzzy Cognitive Maps"- Studies in Fuzziness and Soft Computing, vol. 247/2010, pp.71-87.

Jung, J.J., (2012). Semantic annotation of cognitive map for knowledge sharing between heterogeneous businesses, Expert Systems with Applications vol.39, pp.5857–5860.

Kang I., Lee S. & Cho J., (2004). Using fuzzy cognitive map for the relationship management in airline service, Expert Systems with Applications, vol. 26, no. 4, pp. 545-555.

Khan M.S., Chong A., & Gedeon T., (2000). A Methodology for Developing Adaptive Fuzzy Cognitive Maps for Decision Support, Journal of Advanced Computational Intelligence, vol.4, No.6, pp.403-407.

Khan, M. S., Quaddus, M., (2004). Group Decision Support Using Fuzzy Cognitive Maps for Causal Reasoning, Group Decision and Negotiation vol. 13, pp. 463–480.

Kim, M.C., Kim, C.O., Hong, S.R.& Kwon, I.H., (2008) Forward–backward analysis of RFID-enabled supply chain using fuzzy cognitive map and genetic algorithm, Expert Systems with Applications, vol. 35, no. 3, pp. 1166-1176.

Kontopoulos, E., Bassiliades, N., Antoniou, G., Seridou, A., (2008). "Visual Modeling of Defeasible Logic Rules with DR-VisMo", International Journal of Artificial Intelligence Tools (IJAIT), World Scientific, 17(5), pp. 903-924.

Kosko, B., (1986). Fuzzy Cognitive Maps, Inter. Jour. of Man-Machine Studies, vol. 24, pp.65-75.

Kosko, B., (1992). Neural Networks and Fuzzy Systems, Prentice-Hall.

Lee, K.C., Kim, J.S., Chung, N.H. & Kwon, S.J., (2002) Fuzzy cognitive map approach to web-mining inference amplification, Expert Systems with Applications, vol. 22, no. 3, pp. 197-211.

Lee, K.G. & Lee, S., (2012). A causal knowledge-based expert system for planning an Internet-based stock trading system, Expert Systems with Applications, vol. 39, no. 10, pp. 8626-8635.

Lee, K.G., Lee, H & Lee, N., (2012). Agent based mobile negotiation for personalized pricing of last minute theatre tickets, Expert Systems with Applications, vol. 39, no. 10, pp. 9255-9263.

Lee, S. & Ahn, H., (2009). Fuzzy cognitive map based on structural equation modeling for the design of controls in business-to-consumer e-commerce web-based systems, Expert Systems with Applications, vol. 36, no. 7, pp. 10447-10460.

Lee, S., Yang, J. & Han, J., (2012). Development of a decision making system for selection of dental implant abutments based on the fuzzy cognitive map, Expert Systems with Applications, vol. 39, no. 14, pp. 11564-11575.

Mohr, S.T., (1997).Software Design for a Fuzzy Cognitive Map Modeling Tool, Master's Project, Fall 1997, Rensselaer Polytechnic Institute.

Motlagh, O., Tang, S.H., Ismai,l N. & Ramli A.R., (2012) An expert fuzzy cognitive map for reactive navigation of mobile robots, Fuzzy Sets and Systems, vol. 201, pp. 105-121.

Papageorgiou E.I. & Kannappan A., (2012). Fuzzy cognitive map ensemble learning paradigm to solve classification problems: Application to autism identification, Applied Soft Computing, In Press, Corrected Proof, available online 30 April 2012.

Papageorgiou, E.I., (2012). Learning Algorithms for Fuzzy Cognitive Maps-A review study, IEEE Transactions on Systems Man and Cybernetics (SMC)-Part C, vol. 42, no.2, pp. 150-163.

Papakostas G.A., Koulouriotis D.E., Polydoros A.S. & Tourassis V.D., (2012). Towards Hebbian learning of Fuzzy Cognitive Maps in pattern classification problems, Expert Systems with Applications, vol. 39, no. 12, pp. 10620-10629.

Ramsey, D. & Veltman, C., (2005). Predicting the effects of perturbations on ecological communities: what can qualitative models offer?, Journal of Animal Ecology, vol. 74, pp. 905–916.

Ross, R.G. (2009) Business Rule Concepts, 3rd Edition.

Salmeron, J.L. (2012). Fuzzy cognitive maps for artificial emotions forecasting, Applied Soft Computing, In Press, Corrected Proof, available online 4 February 2012,

Salmeron, J.L., Vidal, R. & Mena, A., (2012). Ranking fuzzy cognitive map based scenarios with TOPSIS, Expert Systems with Applications, vol. 39, no. 3, pp. 2443-2450

Sharp R., (1991). CAT2: An Experimental Eurotra Alternative, Machine Translation 6, pp.215-228.

Song, H.J., Miao, C.Y., Shen Z.Q., Roel W., Maja D.H. & Francky C., (2010). Design of fuzzy cognitive maps using neural networks for predicting chaotic time series, Neural Networks, vol. 23, no. 10, pp. 1264-1275.

Stach, W., Kurgan, L., Pedrycz, W., Reformat, M., (2005). Genetic learning of fuzzy cognitive maps, Fuzzy Sets and Systems, vol. 153, no. 3, pp.371-401.

Stach, W., Pedrycz, W., Kurgan, L.A., (2012), Learning of fuzzy cognitive maps using density estimate, IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics, vol. 42, no. 3, 2012, pp. 900-912.

Stylios, C.D., Georgopoulos, V.C.,. Malandraki, G.A. & Chouliara, S., (2008). Fuzzy cognitive map architectures for medical decision support systems, Applied Soft Computing, vol. 8, no. 3, pp. 1243-1251.

Taber, R., (1991). Knowledge processing with Fuzzy Cognitive Maps, Expert Systems with Applications, vol. 2, no. 1, 1991, pp. 83-87.

Taber, R., Yager, R. R., & Helgason, C. M, (2006). Quantization effects on the equilibrium behavior of combined fuzzy cognitive maps, International Journal of Intelligent Systems, vol. 22, no. 2 , pp. 181 - 202.

Trappey, A.J.C., Trappey, C.V. & Wu, C., (2010). Genetic algorithm dynamic performance evaluation for RFID reverse logistic management, Expert Systems with Applications, vol. 37, no. 11,pp. 7329-7335.

Tsadiras, A.K., Kouskouvelis, I. & Margaritis, K.G., “Using Fuzzy Cognitive Maps as a Decision Support System for Political Decisions”, Lecture Notes in Computer Science series, vol.2563, pp.172-181, Springer-Verlag.

Tsadiras, A. K. & Margaritis, K. G., (1997a). Cognitive Mapping and Certainty Neuron Fuzzy Cognitive Maps, Information Sciences, vol. 101, pp.109-130.

Tsadiras, A. K. & Margaritis, K. G., (1997b). Recursive Certainty Neurons and an Experimental Study of their Dynamical Behaviour, Proceedings of the European Congress on Intelligent Techniques and Soft Computing (EUFIT ’97), Aachen, Germany, pp. 510-515.

Tsadiras, A. K. & Margaritis, K. G., (1999). An Experimental Study of Dynamics of the Certainty Neuron Fuzzy Cognitive Maps, NeuroComputing, vol. 24, pp. 95-116.

Tsadiras, A. K., (2008). A Prolog Based System that assists experts to construct and simulate Fuzzy Cognitive Maps, 5th Hellenic Conference on AI, SETN 2008, Syros, Greece, Proceedings pages 288-300.